“Soil Reinforcement”
Concepts, Applications, Design & Construction

29 & 30 March 2016, ICE UAE

Presented by:
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CONCEPT OF REINFORCED SOIL

without soil reinforcement  with soil reinforcement
TYPES OF SOIL REINFORCEMENTS

- Steel strip (no more used in the gulf countries)
- Geostrip (mainly used for retaining walls in gulf countries)
- Various types Geogrids (extruded, bonded, woven etc)
- Woven geotextiles
### Codes & Guidelines for Soil Reinforcement Applications
(practised in the gulf countries)

<table>
<thead>
<tr>
<th>BS8006-2010</th>
<th>FWHA : 2010</th>
<th>EBGEO : 2010</th>
<th>EN 1997-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>• British Standard</td>
<td>• AASHTO Guidelines</td>
<td>• German Standard</td>
<td>• Eurocode</td>
</tr>
<tr>
<td>• Code of practise for strengthened reinforced soils and other fills</td>
<td>• Design &amp; construction of mechanically stabilised earth walls &amp; reinforced soil slopes, Volume I &amp; II</td>
<td>• Recommendations for designs and analysis of earth structures using geosynthetic reinforcements</td>
<td>• Eurocode 7-Geotechnical Design-Part 1:General Rules</td>
</tr>
</tbody>
</table>
Major applications of Soil Reinforcement as per design codes

- Retaining Walls & Bridge Abutments
- Retaining Slopes
- Soil Nailing
- Embankments
  - On soft soil (like Sabkha in gulf countries)
  - Over piles
  - Over areas prone to subsidence
Major applications of Soil Reinforcement as per design codes

- a) Retaining walls and abutments
- b) Fill slopes
- c) Soil nailed slopes
- d) Basal reinforcement on soft foundations
- e) Basal reinforced piled embankments
- f) Basal reinforcement spanning voids

Subject of Soil Nailed Slopes will be out of scope of this session due to time constraints.
Retaining walls & Slopes definition in terms of inclination angle:

- **Slope**
  - Slope angle up to $70^\circ$

- **Wall**
  - Slope angle greater than $70^\circ$
TYPICAL CROSS-SECTION OF A HIGHWAY RETAINING WALL

- Crash barrier
- Drainage Pipe
- Facing Panel
- Embedment Depth
- Structural Fill
- Backfill
- Soil Reinforcement
- Transverse Drainage Pipe
- Levelling Pad
- Foundation Soil
- Geotextile
Design of Soil Reinforced Retaining Wall

Stability Checks:

1. External Stability is addressed to check against over-turning, sliding and foundation failure.

2. Internal Stability is addressed to determine soil reinforcement spacing, strength & length.

3. Miscellaneous considerations, including wall facing details are addressed.
External Stability checks

[a] Sliding Failure

[b] Overturning Failure

[c] Tilting/Bearing Failure

[d] Slip Failure
Internal Stability checks

1. Two-part wedge analysis

2. Slices Method for Circular Slip Method

- Pull-out and rupture/tear failure
- Compound failure
'Best Geosynthetic Project in Geo-middle East 2015 Conference’
32m high nearly vertical Maccaferri ParaMesh retaining wall for Al Jais Mountain Road Project, Ras Al Khaima, UAE.
Components: (1) Terramesh System & (2) ParaLink 300 high strength geogrid

- Polyethylene sheathing
- Polyester tendons
- Warp element providing strength to geogrid
- Weft element to provide grid-like configuration
- Polyethylene sheathing

Diagram showing the components and their arrangement.
Retaining walls were designed with a 10:1 set back at each 1m high Terramesh course, creating an 84° back slope.

Three intermediate horizontal berms were incorporated to give the wall a lighter visual aspect.

Foundations are 1.5 m deep, while the vertical spacing of Paralink 300 was used as per design requirement.
Completed structure view from highest point (2013).
Retaining Wall for Aramex Ware House Extension in DWC, Dubai, UAE

Gravity gabion type original retaining wall solution

Maccaferri ParaMesh System Reinforced Soil Wall
<table>
<thead>
<tr>
<th>Parameter</th>
<th>ParaMesh Wall</th>
<th>Gabion Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Type</td>
<td>Reinforced Soil Wall</td>
<td>Gravity Wall</td>
</tr>
<tr>
<td>Stone Quantity</td>
<td>2,900 cum</td>
<td>8,800 cum</td>
</tr>
<tr>
<td>Design Life</td>
<td>Designed for 120 years</td>
<td>Not known, but lesser than project requirement of 100 years</td>
</tr>
<tr>
<td>Construction Time</td>
<td>Involves 1,450 pcs of Terramesh units and hence faster</td>
<td>Involves 35,000 pcs of Gabion units and hence slower</td>
</tr>
<tr>
<td>Seismic Resistance</td>
<td>Higher Seismic Resistance</td>
<td>Lesser Seismic Resistance</td>
</tr>
<tr>
<td>Cost</td>
<td>Overall reduction in cost</td>
<td>Relatively Higher</td>
</tr>
</tbody>
</table>
Al Ameen Mosque Parking Development, Muscat, Oman
Terramesh Slope for Landscaping Application
(Under Construction)

MacStARS W
Maccaferri Stability Analysis
of Reinforced Slopes and Walls

Date: 09/22/2014
Folder: Project Title: MME-OMN-2014-044-Landscape retaining wall
Cross Section: File: MME-OMN-2014-044_Design_Seismic

Global stability analysis (Calculation method: Rigid)
C - Serviceability limit state
FS = 1.346
Architectural Walls for Villa Project in Muscat, Oman. (Under Construction)
Segmental Block Walls & Concrete Panel Walls from Iran
Segmental Block Walls & Concrete Panel Walls from Iran
SOIL REINFORCEMENT APPLICATIONS FOR GROUND IMPROVEMENT
Soil Reinforcement in Ground Improvement Applications

Need for Ground Improvement......

• Increase bearing capacity & shear strength of soil

• Reduce compressibility

• Control shrinking and swelling

• Reduce susceptibility to liquefaction

• Reduces pore water pressure

• Decrease settlement
Need for Ground Improvement Techniques

- Increase strength of soil
- Reduce compressibility
- Control shrinking and swelling
- Reduce susceptibility to liquefaction
- Reduces pore water pressure
- Decrease settlement
Methods of Ground Improvement

- Replacement
- Densification
- Soil stabilization
- Consolidation / Dewatering by overloading/stage construction
- Grouting, Soil Nailing
- Pre consolidation by Sand/Stone columns
- **BASAL REINFORCEMENT by high strength Geogrids**
- Combination of above
Basal Reinforcement Applications

d) Basal reinforcement on soft foundations

e) Basal reinforced piled embankments

f) Basal reinforcement spanning voids

Potential weak zones or voids e.g. mining areas, limestone solution cavities, etc.
Geosynthetic Reinforcement Applications in Roads

Scope of this session is to focus only on Basal Reinforcement Applications
Construction of embankments on soft soil (like Sabkha) and organic peat can be critical because of their low shear strength and high compressibility.

<table>
<thead>
<tr>
<th>Consistency</th>
<th>Undrained strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very stiff or hard</td>
<td>&gt;150</td>
</tr>
<tr>
<td>Stiff</td>
<td>100-150</td>
</tr>
<tr>
<td>Firm to stiff</td>
<td>75-100</td>
</tr>
<tr>
<td>Firm</td>
<td>50-75</td>
</tr>
<tr>
<td>Soft to firm</td>
<td>40-50</td>
</tr>
<tr>
<td>Soft</td>
<td>20-40</td>
</tr>
<tr>
<td>Very soft</td>
<td>&lt;20</td>
</tr>
</tbody>
</table>
Contribution of Soil Reinforcement for stability of Embankment
Contribution of Soil Reinforcement for stability of Embankment

Foundation stress condition

Vertical and outward shear stress on foundation soil

unreinforced

reinforced

Fill weight → normal stress

Fill thrust → shear stress

Reinforcement stress condition

Vertical and inward shear stress
Basal Reinforcement Applications on Sabkha Soil

Sabkha is an Arabic expression to describe recent coastal sediments with a high salt content and are characterized by very low bearing capacities and low SPT values. Sabkha soils are widely distributed in the Arabian Peninsula.

Geotechnical properties of Sabkha Soils*
There are several research works available on geotechnical parameters and classification of Sabkha. From the geotechnical design point of view, the simple classifications known are;

• **Muddy Sabkha:** These soils are generally found between +2m and -6m related to present sea level and are all near the coast. These Sabkha soils are relatively young.

• **Sandy Sabkha:** Sandy Sabkha are often sandy layers inter-bedded with sandy mud. These ancient soils can be found as far as 50 km inland

*Courtesy: Jan-Maarten Elias; Building Roads on Sabkha Soils with Geosynthetic Systems*
# Geotechnical Properties of Sabkha Soil

<table>
<thead>
<tr>
<th>Properties</th>
<th>Muddy Sabkhas</th>
<th>Sandy Sabkhas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage Fines</td>
<td>25 to 95</td>
<td>5 to 25</td>
</tr>
<tr>
<td>Salt content (%)</td>
<td>2 to 18</td>
<td>2 to 15</td>
</tr>
<tr>
<td>Water content (%)</td>
<td>25 to 90</td>
<td>4 to 40</td>
</tr>
<tr>
<td>In-situ density</td>
<td>1.0 to 1.35</td>
<td>1.3 to 1.85</td>
</tr>
<tr>
<td>Internal friction</td>
<td>$0^0$ to $22^0$</td>
<td>$20^0$ to $35^0$</td>
</tr>
<tr>
<td>Percentage of Ca CO$_3$ (%)</td>
<td>20 to 90</td>
<td>&gt; 30</td>
</tr>
<tr>
<td>Plasticity index</td>
<td>0 to 40</td>
<td>Non plastic</td>
</tr>
<tr>
<td>Cohesion (kN/m$^2$)</td>
<td>0 to 55</td>
<td>Zero</td>
</tr>
<tr>
<td>Compression index</td>
<td>0.4 to 0.95</td>
<td>Zero</td>
</tr>
<tr>
<td>S.P.T. values (blows)</td>
<td>0 to 4</td>
<td>2 to 10</td>
</tr>
<tr>
<td>Static cone resistance (MN/m$^2$)</td>
<td>0.2 to 2</td>
<td>1 to 6</td>
</tr>
<tr>
<td>Bearing capacity (kN/m2)</td>
<td>15 to 30</td>
<td>30 to 60</td>
</tr>
</tbody>
</table>

*Table 1. Typical soil properties of muddy and sandy sabkhas [2]*
Problematic Muddy Sabkha Soil Found in Gulf Countries

‘Muddy Sabkha’ in UAE; adjacent to Mafraq Ghwaifat Highway

‘Muddy Sabkha’ in Oman; along the shores in Duqm Special Economic Zone
Design Checks for Stability

Local Stability

Rotational Stability

Foundation Extrusion Stability

Lateral Sliding Stability

Global Stability

Excessive Settlement
Basal Reinforced Piled Embankments

- Control on settlement of embankment
- Improved Bearing Capacity
- Rapid method of construction
Basal Reinforcement Over Piles is preferred over simple Basal Reinforcement Technique at Bridge Ramps.
Basal Reinforcement Spanning Voids

Problematic when embankments, roads or building are to be constructed above potential sink hole locations or areas that cannot be compacted due to presence of utilities or other constraints.

Sinkhole nearly swallows Land Cruiser in Al Ain
Collapse of pavement opens up a hole more than two metres deep and three metres wide
By Mariam Alyammahi
Published Tuesday, October 07, 2014

MUSCAT - A sinkhole has opened up in Hafeet in Buraimi, drawing people from all across the sultanate.
Sequence of events no reinforcement

- Embankment
- Subsoil
- Void

Basal Reinforcement Spanning Voids
Sequence of events with reinforcement

Basal Reinforcement Spanning Voids

Embankment

Subsoil

Void

Surface depression

Reinforcement deflects
Site Criteria & tender solution

Out of the 20km of road length, approximately 8km of road embankment is to pass through Sabkha soil of depth varying from 2m to 6m.

The road embankment will have a maximum height of 3m.

As per tender documents, for locations with Sabkha depth ≤4m, soil replacement for full depth of Sabkha required. For locations with Sabkha depth greater than 4m, Stone columns to be adopted.

Weak muddy Sabkha with Cu as low as =10KPa & CBR less than 1.0
Basal Reinforced Embankment for Service Corridor Project, Duqm, Oman.
## Basal Reinforced Embankment for Service Corridor Project, Duqm, Oman.

<table>
<thead>
<tr>
<th>Design Type</th>
<th>Without basal reinforcement</th>
<th>With basal reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static FOS (BS 8006, ultimate limit state)</td>
<td>1.0</td>
<td>0.334</td>
</tr>
<tr>
<td>Seismic FOS (BS 8006, serviceability limit state)</td>
<td>1.3</td>
<td>0.367</td>
</tr>
</tbody>
</table>
New villas proposed in Jumeirah Open Beach. Due to existing utilities, some location cannot be vibro-compacted that creates a Void like Condition with limited support from subsoil.
Geogrid Soil Reinforcement Technique To Improve Global Stability of Additional 6m High Filling in Blue Water Island Project, Dubai, UAE.

3-D Rendering of Initial Master plan of Blue Water Island Project
Geogrid Soil Reinforcement Technique To Improve Global Stability of Additional 6m High Filling in Blue Water Island Project, Dubai, UAE.

Failure in Post Liquefaction Case in Overall Stability Due to Additional 6m Fill
Geogrid Soil Reinforcement Technique To Improve Global Stability of Additional 6m High Filling in Blue Water Island Project, Dubai, UAE.

POSSIBLE STABILIZATION OPTIONS CHECKED & PROPOSED BY CLIENT

Option 1: Top Filling to be made of Cement Stabilized Sand
Geogrid Soil Reinforcement Technique To Improve Global Stability of Additional 6m High Filling in Blue Water Island Project, Dubai, UAE.

POSSIBLE STABILIZATION OPTIONS CHECKED & PROPOSED BY CLIENT

Option 2: Extension of Quarry Run Trench at Toe of Revetment
Geogrid Soil Reinforcement Technique To Improve Global Stability of Additional 6m High Filling in Blue Water Island Project, Dubai, UAE.

POSSIBLE STABILIZATION OPTIONS CHECKED & PROPOSED BY CLIENT

Option 3: Grouting Liquefiable Sand Layer Below the Breakwater Core
Geogrid Soil Reinforcement Technique To Improve Global Stability of Additional 6m High Filling in Blue Water Island Project, Dubai, UAE.

POSSIBLE STABILIZATION OPTIONS CHECKED & PROPOSED BY CLIENT

Option 4: New Filling at top to be stabilized with high strength geogrids
## Geogrid Soil Reinforcement Technique To Improve Global Stability of Additional 6m High Filling in Blue Water Island Project, Dubai, UAE.

### SUMMARY OF FACTOR OF SAFETY (FOS) TARGETTED VS ACHIEVED FOR GLOBAL STABILITY DESIGN OF BLUE WATER PROJECT

<table>
<thead>
<tr>
<th>Design Type</th>
<th>Type of Design (representing Sections 1, 2 &amp; 3)</th>
<th>Analysis Type</th>
<th>Static Case</th>
<th>Seismic Case</th>
<th>Post Liquefaction Case</th>
<th>Extreme Load Case</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With Geogrid Stabilization</td>
<td>Global Stability Check</td>
<td>≥1.5</td>
<td>2.447</td>
<td>≥1.1</td>
<td>1.610</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slip Plane Above Liqueifiable Layer</td>
<td>≥1.5</td>
<td>2.609</td>
<td>≥1.1</td>
<td>1.591</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Internal Stability</td>
<td>≥1.5</td>
<td>2.135</td>
<td>≥1.125</td>
<td>2.025</td>
</tr>
<tr>
<td></td>
<td>Without Geogrid Stabilization</td>
<td>Global Stability Check</td>
<td>≥1.5</td>
<td>1.759</td>
<td>≥1.1</td>
<td>1.286</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slip Plane Above Liqueifiable Layer</td>
<td>≥1.5</td>
<td>1.751</td>
<td>≥1.1</td>
<td>1.492</td>
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<tr>
<td></td>
<td>(representing Sections 4, 5 &amp; 6)</td>
<td>With Geogrid Stabilization</td>
<td>≥1.5</td>
<td>2.369</td>
<td>≥1.1</td>
<td>1.604</td>
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<tr>
<td></td>
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<td>Slip Plane Above Liqueifiable Layer</td>
<td>≥1.5</td>
<td>2.751</td>
<td>≥1.1</td>
<td>1.773</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Internal Stability</td>
<td>≥1.5</td>
<td>4.597</td>
<td>≥1.125</td>
<td>2.984</td>
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<tr>
<td></td>
<td>(representing Sections 4, 5 &amp; 6)</td>
<td>With Geogrid Stabilization</td>
<td>≥1.5</td>
<td>1.611</td>
<td>≥1.1</td>
<td>1.193</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slip Plane Above Liqueifiable Layer</td>
<td>≥1.5</td>
<td>1.587</td>
<td>≥1.1</td>
<td>1.179</td>
</tr>
</tbody>
</table>

*ASD: Allowable Stress Design

**STATIC CASE DESIGN:** With Mean Sea Level (MSL) of +1.1m.....Tidal Lag of 0.5m.....UDL=14KPa

**SEISMIC CASE DESIGN:** With Mean Sea Level (MSL) of +1.1m.....Fh=0.105, Fv=0.0525.....UDL=9KPa

**POST LIQUEFACTION CASE DESIGN:** With Mean Sea Level (MSL) of +1.1m.....Reduced Friction angel for Liqueifiable Sand Layer = 2deg.....UDL=14KPa

**EXTREME LOAD CASE DESIGN:** With HAT=+2.3m.....LAT=0.1m.....Tidal Lag of 0.5m.....UDL=14KPa
Geogrid Soil Reinforcement Technique To Improve Global Stability of Additional 6m High Filling in Blue Water Island Project, Dubai, UAE.

Global Stabilization with high Strength Geogrids accommodating utilities
Health & Safety Aspects Related to Soil Reinforcement Application’s Design & Construction

Generally, the design shall produce contract documents to enable works to be constructed which fulfill the specified requirements with respect to safety, serviceability, economy and durability, taking into account the expected service life.

The following documentations and practices are required to be approved prior to execution;

Material Safety Data Sheets for each type of Soil Reinforcement

Method Statements & Risk Assessments

Lift Plans & Enabling Works

Safety Instructions related to installation
Thank you for your presence & support! Questions????